THE TWO TYPES OF FLARE-ASSOCIATED FILAMENT ERUPTIONS

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Abstract. Using 15 years of high-resolution solar film obtained at Big Bear Solar Observatory we studied flare-associated filament eruptions. In addition to the 'classical' type eruption consisting of expansion and breakup, we find evidence of another type where a layer is 'shed' from the filament and erupts while the inversion line filament below (or, what is left of it) remains in place. Both types of eruptions are presented in the paper. It is hoped that the new evidence will shed new light on the understanding of the role of filaments in flares.

1. Introduction

Flares and coronal mass ejections are closely related to filament eruptions. Filament eruptions in active regions are intimately related to solar flares (Martin, 1980), but not every such eruption results in a coronal mass ejection. On the other hand, the eruptions of quiescent filaments (prominences), which may not always have an associated chromospheric flare, are intimately related to coronal mass ejections (Munro *et al.*, 1979). It is as though the eruptions of active region filaments may or may not affect a large part of the corona above them, whereas the eruptions of quiescent filament, being at much greater heights than active region filaments to begin with, disturb a greater part of the solar atmosphere above.

An understanding of the physical process of filament eruptions is crucial to the understanding of the magnetic topology in and around the filament, which, as Pneuman (1983) pointed out may well be one of the central problems of solar activity.

Filaments are familiar Hα absorption features of the chromosphere and corona. They mark the inversion line of the photospheric magnetic fields. Although many filament eruptions precede the onsets of flares, it is by no means a rule. Filament eruptions are also observed to take place simultaneously with flares, during flares, or as a result of the spread of the flares. Some filaments are observed to remain in place throughout the flare. In other cases flares are observed without any inversion line filament. The diverse behaviour of the flare-associated filament eruptions raises the inevitable question of the role of the filament and its eruption in the flare scenario. However, the problem cannot be meaningfully addressed without an understanding of the physical process of filament eruptions. To this end, better observational understanding of the physical process of eruptions is crucial.

Flare-associated filament eruptions have been studied for nearly four decades with low-resolution data by many investigators. For a summary, see the review by Martin (1980, and references therein). Essentially, the eruption process was observed to consist

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of the extension of a filament in the shape of a loop, the breaking up of the loop at the top, and the blowing off and disappearance of the filament material. This basic picture remains largely unchanged even with the advent of high-resolution data and space-borne observations during Skylab and the Solar Maximum Mission.

Although flare-associated filament eruptions are common occurrences, good and revealing observations are hard to come by despite years of high-resolution optical data. This is because filament eruptions are difficult to observe even under the best circumstances. They happen quickly and are often obstructed by flaring material along the line-of-sight. Most filament eruption observations offer no more useful details than the basic picture described earlier; some are too complex to understand. However, a number of cases, collected from 15 years of high-resolution solar film from Big Bear Solar Observatory, offer new information on the eruption process. The high-resolution data reveal a new type of eruption where a layer is shed or peeled off from the active region inversion line (IL) filament. This layer then erupts while the IL filament below remains in place. The events of this type are presented in Section 2. For comparison, the 'classical' type of eruption is presented in Section 3. A summary and a discussion are offered in the final section.

2. Peeling and Eruption of a Filament Layer – a Different Type of Filament Eruption

2.1. An Overview

This is the type of eruption in which the inversion line filament remains in place but a layer of it is seen to separate from the parent filament. The severed layer is displaced from the parent IL filament such that it is at a higher altitude and generally does not lie directly above the photospheric magnetic inversion line.

This transient layer may erupt as it peels off the parent filament, or it may stay there for tens of minutes before erupting. The manner in which the layer erupts varies. In one case, a loop-like layer took off as a unit. In most cases, however, the mass in the layer seems to move along presumed expanding, partially relaxed field lines. Often chromospheric brightenings may be seen at one end or both ends of the field lines when part of the mass falls downward toward the surface.

Of the 15 events we collected where the observations offer details of the eruption process, eight fall into the 'eruption of a filament layer' category. The rest belong to the 'classical' type of eruption. Because of the selection criteria, the numbers bear no statistical significance.

2.2. Examples

2.2.1. *26 April, 1979*

In this event shown in Figure 1, the separation of a layer from the inversion line filament was evident at 19 : 55 : 22 UT. A two-ribbon flare began at 19 : 58 UT. The IL filament,

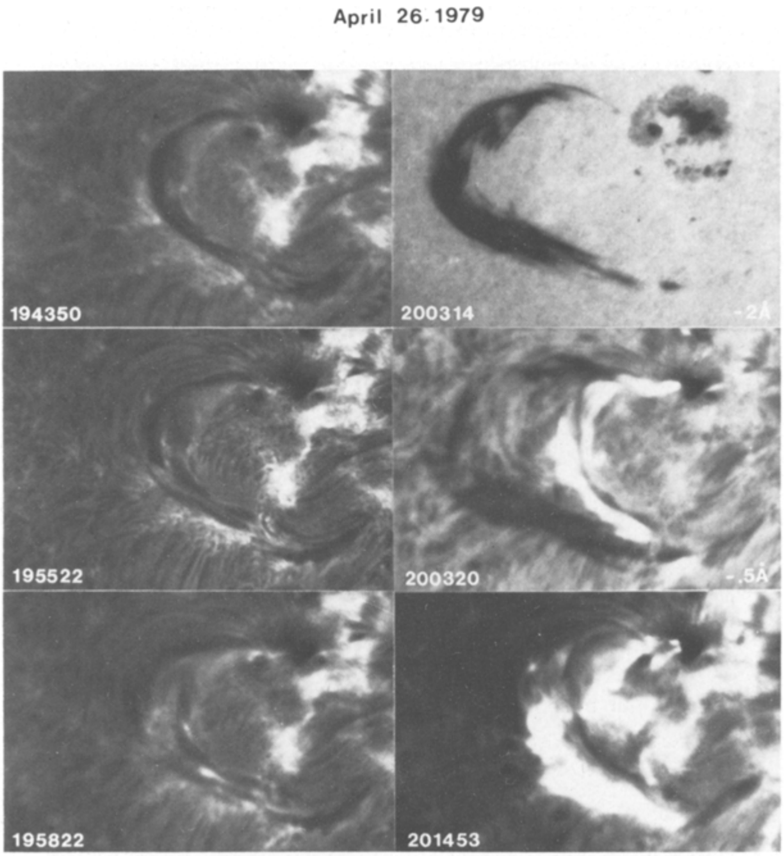

Fig. 1. A layer of the inversion line filament is seen to separate from the parent filament. The loop-shaped layer moved away as the class 1/C7 flare began at N11 E31. The IL filament remained in place throughout the flare. A metric type II burst was observed 20 : 15–20 : 35 UT. But no coronal mass ejection was observed despite adequate coverage.

seen here in + 0.5 Å at 20 : 03 : 20 UT, remained in place throughout the flare, even though it was not as visible in the line center until the two flare ribbons had receded sufficiently from the inversion line. The loop-shaped top layer, seen here in 2 Å blue wing at 20 : 03 : 14 UT, in the meantime retained its shape and moved away as a unit until it disappeared outside of the field of view at 20 : 10. Interestingly, no associated coronal mass ejection for this event was observed despite adequate Solwind coronagraph coverage (Sheeley, 1985, private communication).

2.2.2. *22 June, 1980*

This is a very small region and the event was the second one of a similar kind observed on the same day. Figure 2 shows that a layer of the IL filament rose and moved across to the right to a less sheared orientation. At 22 : 11, a small but impulsive flare began and the layer blew off in the upper left direction. A small burst with maximum at 20 : 14 : 15 was observed by the SMM Hard X-Ray Burst Spectrometer.

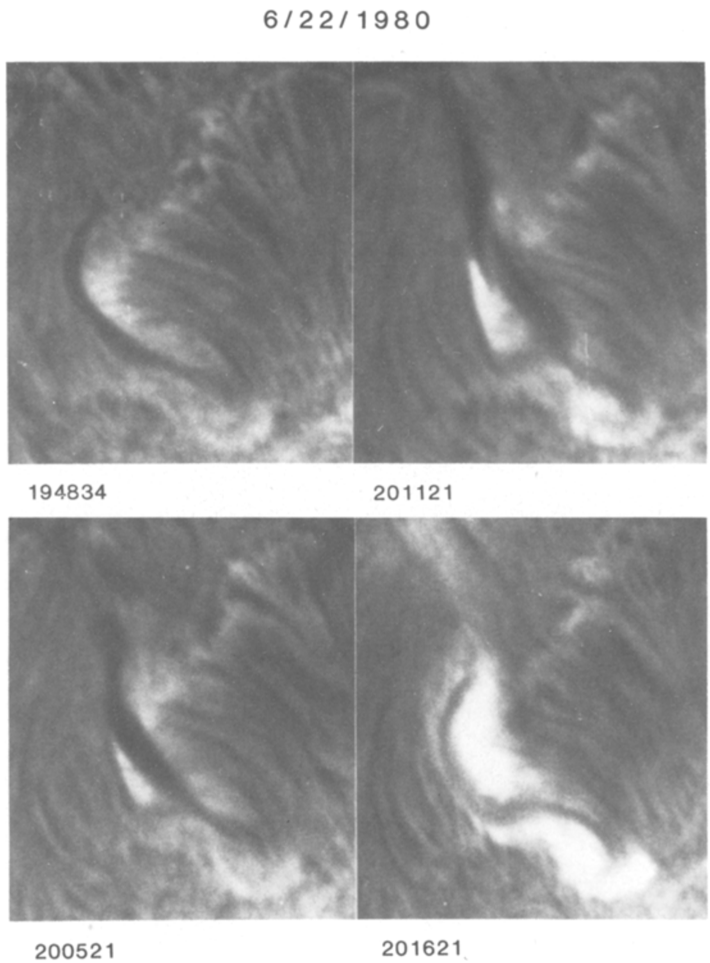

Fig. 2. A layer of the IL filament rose and separated from it. The eruption of this layer resulted in an impulsive subflare 20 : 05–20 : 14–20 : 32, located at S23 E14.

2.2.3. *2 October, 1979*

This sequence in Figure 3 shows that a layer of a filament apparently came off as a result of a flare nearby. Unlike the others, in this case the eruption of the severed layer did not result in a flare.

2.2.4. *9 October, 1977*

The sequence in Figure 4 shows how a segment of the top layer separated from the IL filament as the flare began. The layer then brightened (15 : 56 : 32), became completely detached (16 : 00 : 21) and then drifted away. Note again that the IL filament remained in place throughout the flare. Three hours later, another segment of the IL filament thickened and at 19 : 29 : 13 UT the top layer of that segment became detached and erupted, accompanied by a very small flare.

10/2/1979

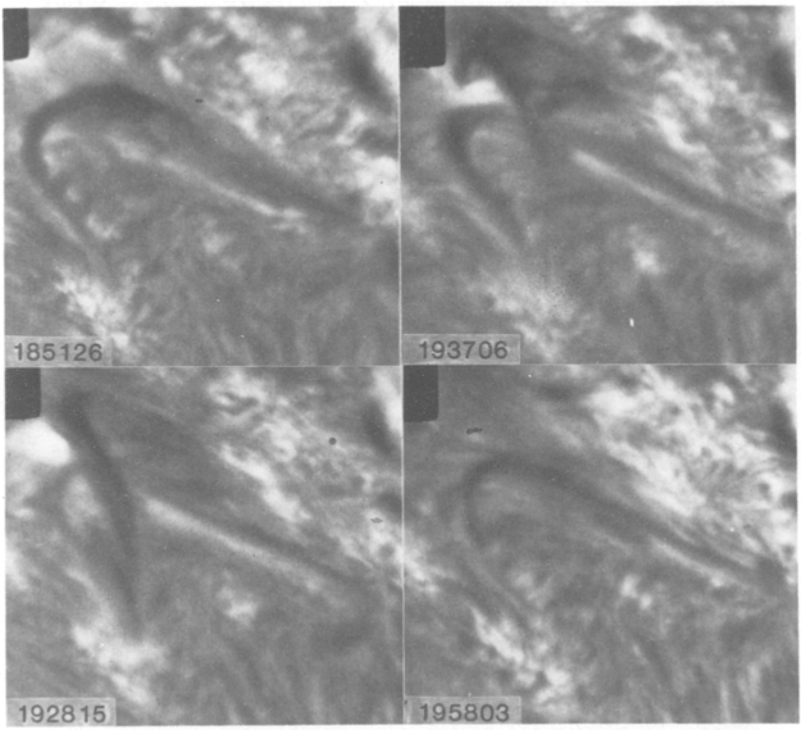

Fig. 3. This sequence shows that a layer of the filament peeled off and erupted with no associated flare except a single blob of brightening.

2.2.5. *16 May, 1983*

This event shown in Figure 5 consisted of two flares, or two stages of one flare. The top layer appeared as a hump at 15 : 29 : 23, and became separated from the IL filament as a result of the first flare. The elevated layer seemed to indicate a less sheared field in the 16 : 24 : 12 frame than that of the IL filament below. This layer then erupted with a second flare (16 : 36 : 12), leaving the IL filament intact below (17 : 58 : 47).

2.2.6. *9 June, 1979*

This event (Figure 6) is very similar to the 16 May, 1983 event just presented. They differ only in perspective due to different longitudes at which the observations were made. The first frame shows the flare on 8 June (22 : 20–22 : 36–23 : 18) in progress. At 23 : 39, a layer is seen being shed. The second flare, began at 23 : 44 as the top layer lifted from the IL filament.

In this 9 June event, unlike the others, the transient layer did not erupt and disappear but began to *descend* at 00 : 18 and completely merged with the IL filament by 00 : 43!

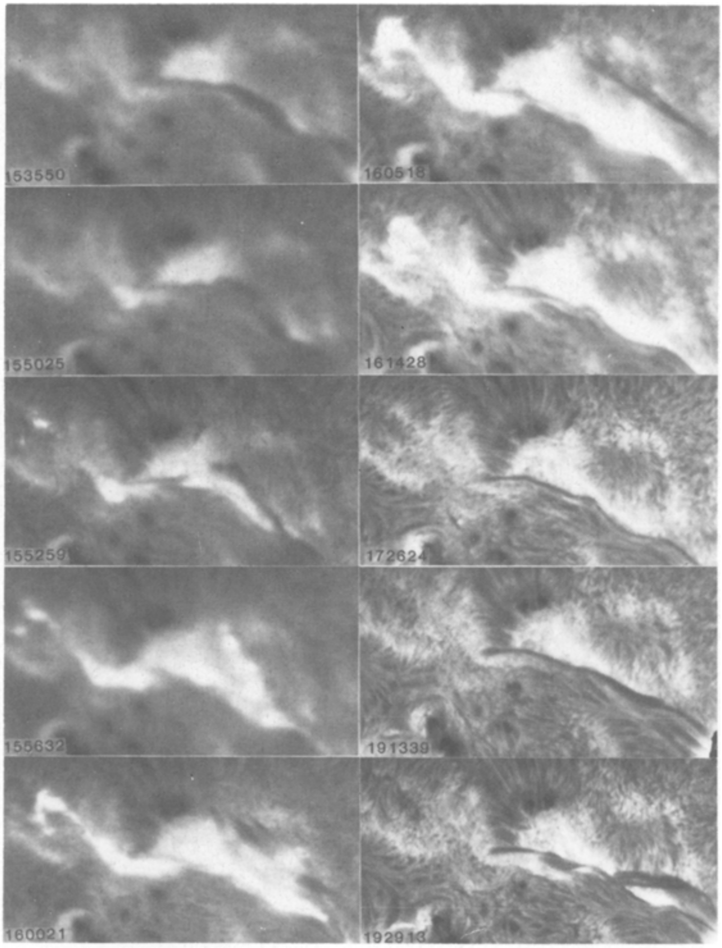

Fig. 4. This sequence shows how the top layer of a segment of the parent filament broke apart from it, then erupted. The associated subflare was located at N13 E36. Note that three hours later (last frame) another layer became detached and erupted with a small flare.

2.2.7. *4 March, 1981*

A detached and elevated layer of the filament (arrow) not seen at the end of the previous day at 23 : 30 was present when observation began at 07 : 22 at the Tel Aviv station (Figure 7). We infer that the layer 'grew' out of the IL filament just as in the other cases we witnessed. The transient layer began to erupt at 07 : 25, slowly in the first 80 min then speeding up. A class 1 flare began as the last trace of the detached layer disappeared.

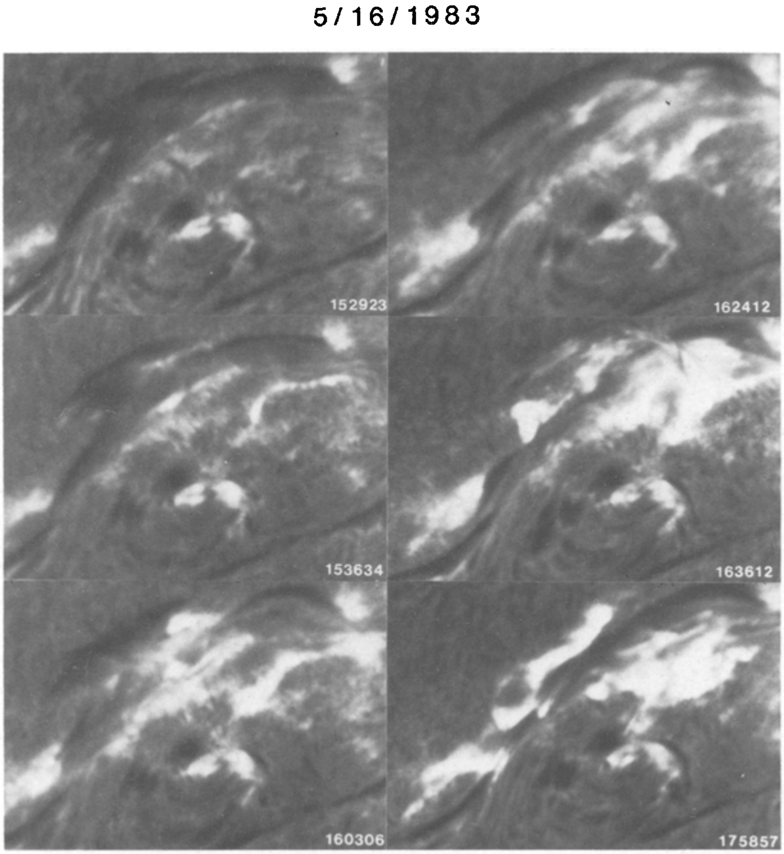

Fig. 5. The top layer not yet separated from the parent filament appeared as a hump at 15 : 29 : 23 UT. The separation was complete as a result of a subflare at 16 : 24 : 12 UT. Note that the layer seemed to be in a less sheared configuration than the parent IL filament below. A class 0/C5 subflare at S29 W54 accompanied the eruption of this layer.

3. Filament Eruption of the 'Classical' Type

In contrast to the eruption of a layer of filament discussed in the last section, in this 'classical' type of eruption the entire filament erupts. The extension of the filament loop before breakup of the field lines is observed in this case. We present two events of this kind. Both occurred near the limb providing an excellent three-dimensional perspective of the eruption process.

Figure 8 shows an eruption on 10 October, 1971 at N12 W73. The 1/M5 flare appeared to begin under the filament. As the flare expanded, the filament extended as though pushed from underneath. With both feet anchored, the filament expanded until strands of the field lines began to break open at the top at various heights. The highest loop-visible reached about 100 000 km. By 01 : 00 UT no closed loops were visible. The

6/9/1979

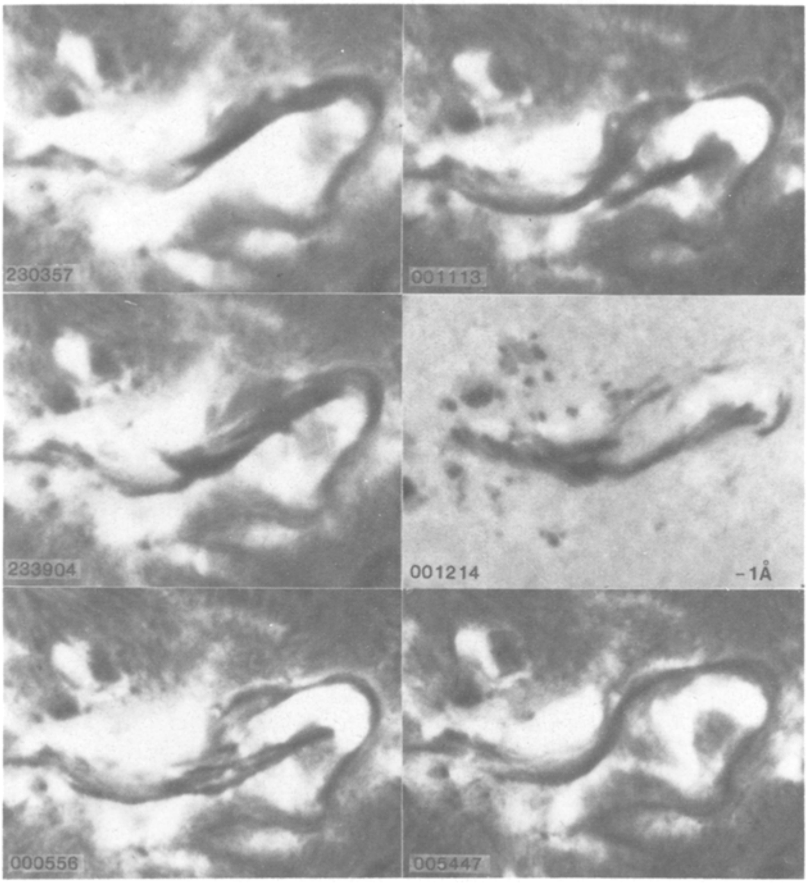

Fig. 6. Viewed at a different perspective, this event is presumably similar to the one in Figure 5. The associated 1/M1 flare was located at N23 W32. Unlike the others, however, in this event the severed layer did not erupt upward and disappear but descended and merged with the parent filament as shown in the last frame.

observation ended at 01 : 04 with both feet of the filament still firmly anchored to the surface.

Figure 9 shows an event very similar to the one just discussed. This more impulsive 2/X1.9 flare was at N16 W65. Again the flare seemed to begin from under the filament. As the filament extended, strands of the filament loops popped open at the top. Both feet of the filament were anchored to the surface as indicated by the arrows in the 00 : 55 : 44 frame. The top of the visible loop is estimated at 250 000 km. (At this point the telescope was repositioned and exposure was increased to enhance the visibility of fainter objects above the limb.) Mass was seen to continue to ascend upward. However, we are uncertain as to the origin of this mass since the geometry of the loop looked

3/4/1981

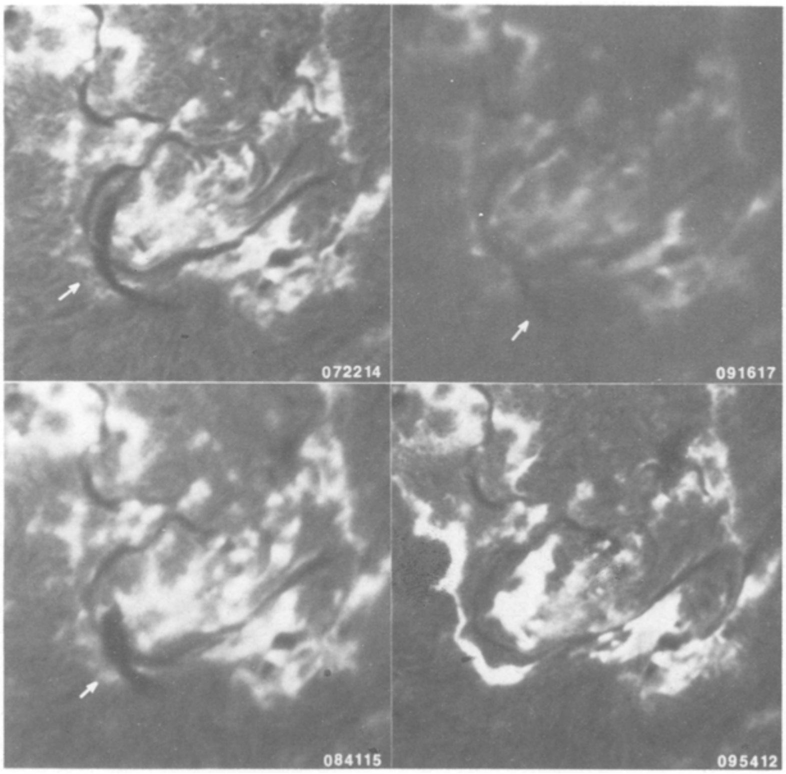

Fig. 7. Arrow indicates the layer already separated from the IL filament when the observation began. This class 1 flare (peak soft X-ray intensity is not known due to data gap) began at 09 : 23, after the eruption of the detached layer completed. We infer that the layer originated from the parent IL filament in the same way as in the other cases. The flare at S17 W36 lasted until 12 : 30 UT with maximum at 09 : 46 UT.

different. Nevertheless we find it worthwhile to report it here since it offers a rare chance to observe an eruption from the side; we probably could not interpret it correctly had it occurred on the disk. At $\sim$ 01 : 00 UT slanted loops appeared. Material was seen to move up one leg and down another along the individual loops (reminiscent of spiralling of the falling material in flare spray described by Tandberg-Hanssen *et al.*, 1980). At the same time, the loops themselves are seen to descend back toward the surface (see 01 : 19 : 40 frame). When the flare was over, the filament (seen in the first frame at 00 : 07) was gone.

The two near-limb events just presented show that the feet of the filament are rooted in the solar surface during the eruption process and at least some mass is seen to return to the surface. It is not known whether the mass in the expanding phase of the eruption comes from the filament itself, i.e., with no net increase in mass, as in the case of a stretched rubber band; or, the mass comes from a 'live' source in the lower atmosphere where the feet of the filament are rooted, as in the case of a surge.

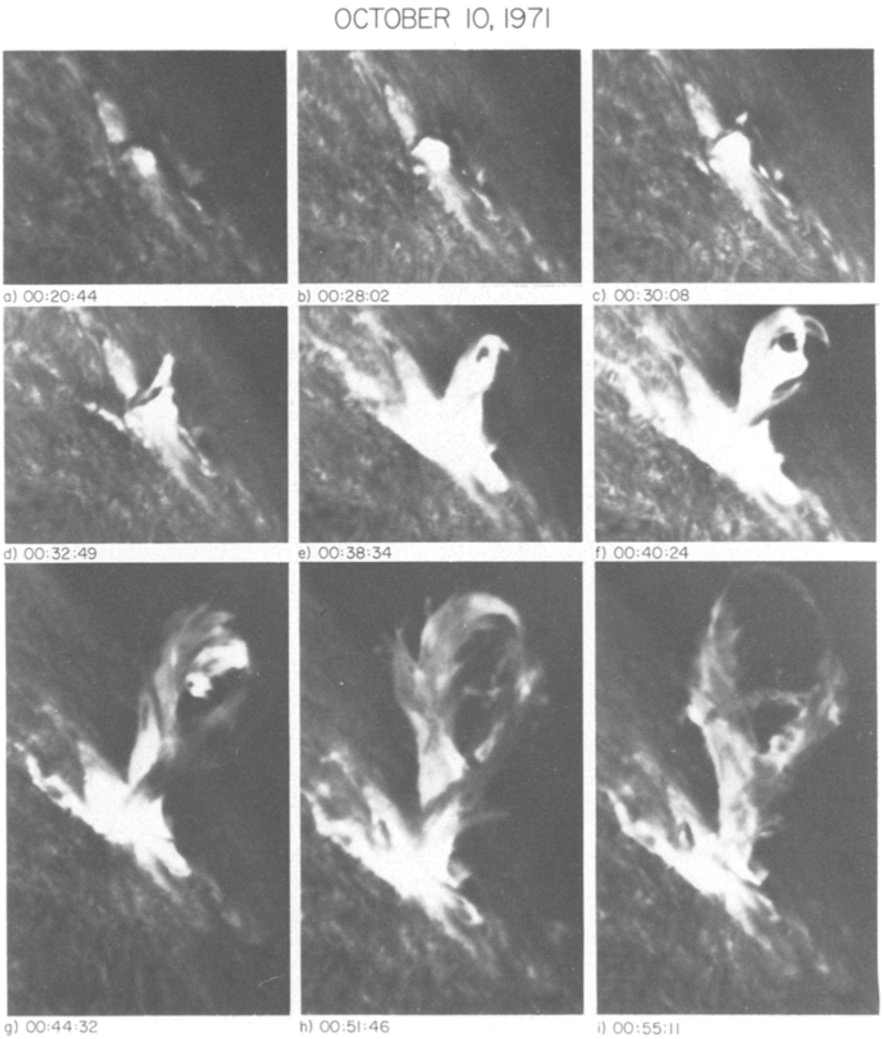

Fig. 8. At W73, this filament eruption/flare illustrates the 'classical' type of eruption where the filament expanded, followed by breakup and disappearance. Note that the feet of the filament remained anchored to the solar surface throughout the expansion and breakup. Note also that the flare began under the filament. The filament extended as if pushed from underneath. A ~M5 in maximum soft X-ray flux was measured by OSO-7.

4. Discussion

We have shown that there are two ways filaments may erupt. We now discuss the implications and problems brought on by the new evidence.

4.1. Do filaments really re-form during flares?

In the eruption of a filament layer (Section 2), a layer becomes detached from the IL filament. When this detached layer erupts, the IL filament below (or what is left of it)

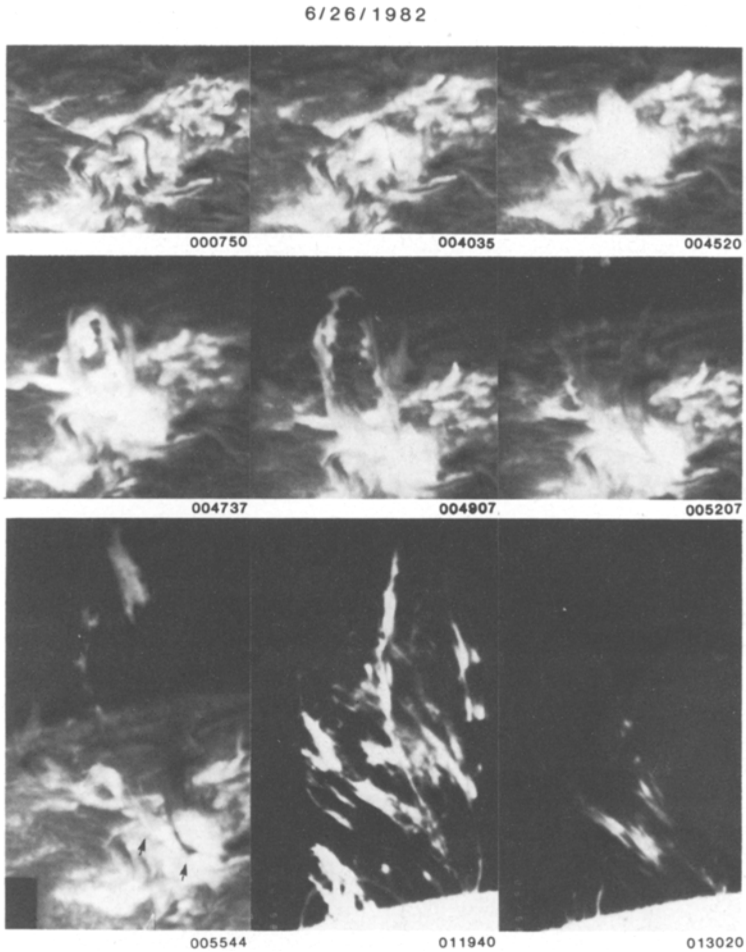

Fig. 9. This 26 June, 1982 event is very similar to the 10 October, 1971 event. The arrows (00 : 55 : 44 UT) indicate the feet of the filament. See text for detail. When the flare ended, the filament (see at 00 : 07 : 50 UT) was gone. The impulsive 2/X1.9 flare was located at N16 W65. Two hard X-ray bursts were recorded, the second was accompanied by a radio burst up to 35 GHz.

remains in place. Because of the obstruction of flare ribbons, this information is lost in full disk low-resolution data. Instead, the observer sees the eruption of a filament and when the flare ribbons separate sufficiently from the magnetic inversion line, he sees 'another' filament. This explains most, if not all, of the many reports on 'reformation' or 'reappearance' of filaments during flares in the literature.

4.2. Large flares associated with eruptions of a filament layer

The eruptions of a layer of detached IL filaments have been observed with a few large well-known flares, although they were not understood as such at the time. One such event involved a 6 arc min long layer crisscrossing the IL filament at two points, whose

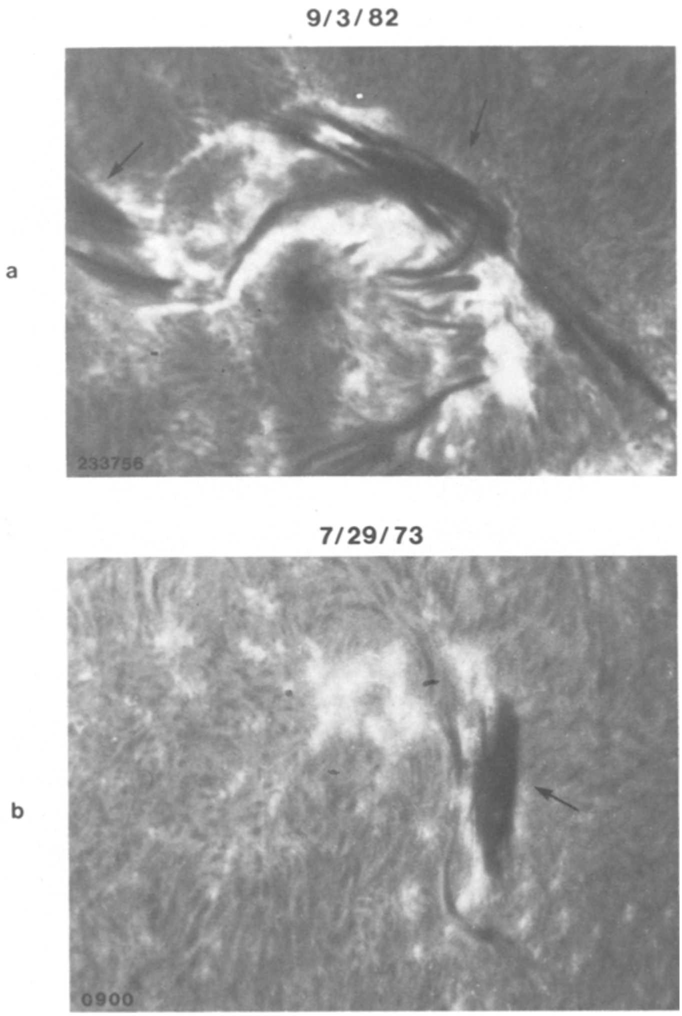

Fig. 10. Two class 3 flares associated with eruptions of a filament layer. In frame (a) arrows show segments in the early stage of an elevated layer above the inversion line filament that eventually grew to be 6 arc min long on 4 September, 1982. In frame (b) the arrows indicates the massive layer hanging over the IL filament before its eruption and the class 3 flare on 29 July, 1973.

eruption on 4 September, 1982 resulted in class 3 flare lasting 19 hr (see the Frontispiece *Solar Phys.* **83**, 2; Harvey and Recely, 1984; Morishita, 1985). Arrows in Figure 10(a) show segments of that layer above the IL filament not yet joined together. Re-examination of our full disk film reveals that the first segment of the layer began to rise out of the sinuous IL filament at 23 : 18 UT. Other segments, elevated and inclined from the photospheric magnetic inversion line, appeared later and joined together to become 6 arc min long by 00 : 32 UT on 4 September.

In another example, on 29 July, 1973 (Martin, 1979; Moore and LaBonte, 1980) the eruption of a detached layer of filament appearing as a dark mass 20000 km above the

IL filament, shown in Figure 10(b), resulted in the well-known Skylab class 3 flare. We infer that the layer was shed from its parent IL filament below in the same way as the others between 02 : 00 and 07 : 10, the data gap between our two sets of film records.

4.3. Evidence of Severed Filament Layer in Soft X-Rays

In a recent comprehensive survey of Skylab soft X-ray images, Webb (1985) reported a significant number of preflare X-ray enhancements in the shapes of loops, knots, and sinuous features that are generally displaced from the flare sites. Hα absorption features were found in half of these cases. Some of these preflare X-ray enhancements could well be caused by the detached layer of filaments, since thermal X-ray enhancements were observed to coincide with preflare filament disruptions (Roy and Tang, 1975).

4.4. What Does the New Evidence Imply?

If filament eruption is triggered from underneath by instability in the magnetic field lines, then it may be that the two kinds of eruption are different only in the location of the triggering instability. If it is under the filament, the whole filament will erupt; if the instability is imbedded within the filament, only the top layer will erupt. However, this does not explain why and how a severed layer becomes suspended high above the inversion line filament stably for up to tens of minutes.

Does the presence of this elevated layer signify a topological change in the magnetic field at that height to a more sheared configuration? When the severed layer erupts and the inversion line filament remains underneath, does this imply the flare disturbance leaves the lower layer of the atmosphere unperturbed? These and other questions about the physics of the inversion line magnetic field, in view of the new findings presented here, cannot be answered without a thorough theoretical consideration which is beyond the scope of this paper.

We may not have captured all facets of filament eruptions at present. As the level of understanding increases, future observations will undoubtedly reveal more. Nevertheless, we hope the new evidence unveiled here will inspire a new generation of models for theoretical consideration and interpretation of the magnetic topology in and around the filament and its role in the flare scenario.

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